NANOSCIENCE AND TECHNOLOGY AT THE AIR FORCE RESEARCH LABORATORY (AFRL)

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AIR FORCE RESEARCH LABORATORY VISION
We defend America by unleashing the
power of innovative air and space technology

We are the Air Force Research Laboratory

Brigadier General Perry L. Lamy
Commander

Ten Directorates

Air Vehicles Directorate
Space Vehicles Directorate
Munitions Directorate
Sensors Directorate
Propulsion Directorate
Materials & Manufacturing Directorate
Directed Energy Directorate
Human Effectiveness Directorate
Information Directorate
AFOSR

Our Score Card

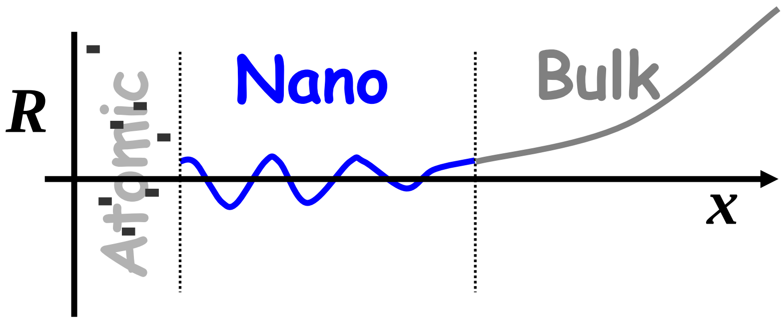
- 5397 government personnel
  - 4388 civilian
  - 1009 military
- 3000 on-site contractors
- $1.3B annual S&T budget
- $500M annual customer budget

OUTLINE

- AN AF PERSPECTIVE OF NANOTECHNOLOGY
- NANOSCIENCE AND TECHNOLOGY IN AFRL: PAST AND PRESENT
- A STRATEGIC PLAN FOR THE FUTURE
- SUMMARY

NanoScience and Technology
Defining Features

Nanoscience provides a pathway to new physical responses and behaviors



Opto-electronic

Property	Critical Length
Electron Wavelength	10-100 nm
Inelastic Mean Free Path	1-100 nm
Quantum Well	1-100 nm
Evanescent Wave Decay Length	10-1000 nm

Structural

Property	Critical Length
Defects	1-100 nm
Grain Boundary	1-10 nm
Grain Size	1-100 nm
Dislocation Interaction	1-100 nm
Crack Tip Radius	1-100 nm
Critical Nucleus	1-10 nm

Defining Features

- **Provides behavior different than either bulk or atomic responses**
- **Characterized by non-bulk scaling or approaching a singularity**
- **Critical length depends upon dominant morphological length scale and property of interest**
- **Physical basis resides in coupling morphological dimensions with critical length scale and/or introducing high surface-to-volume ratio**

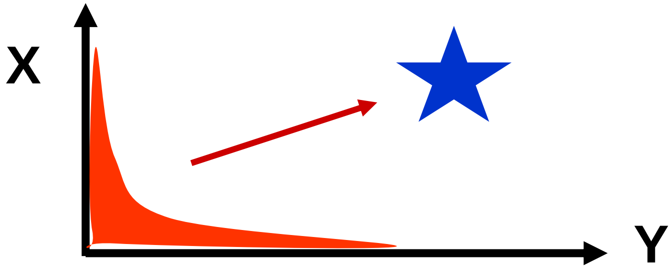
Impact to Materials and Devices

Nano-Enabled Materials

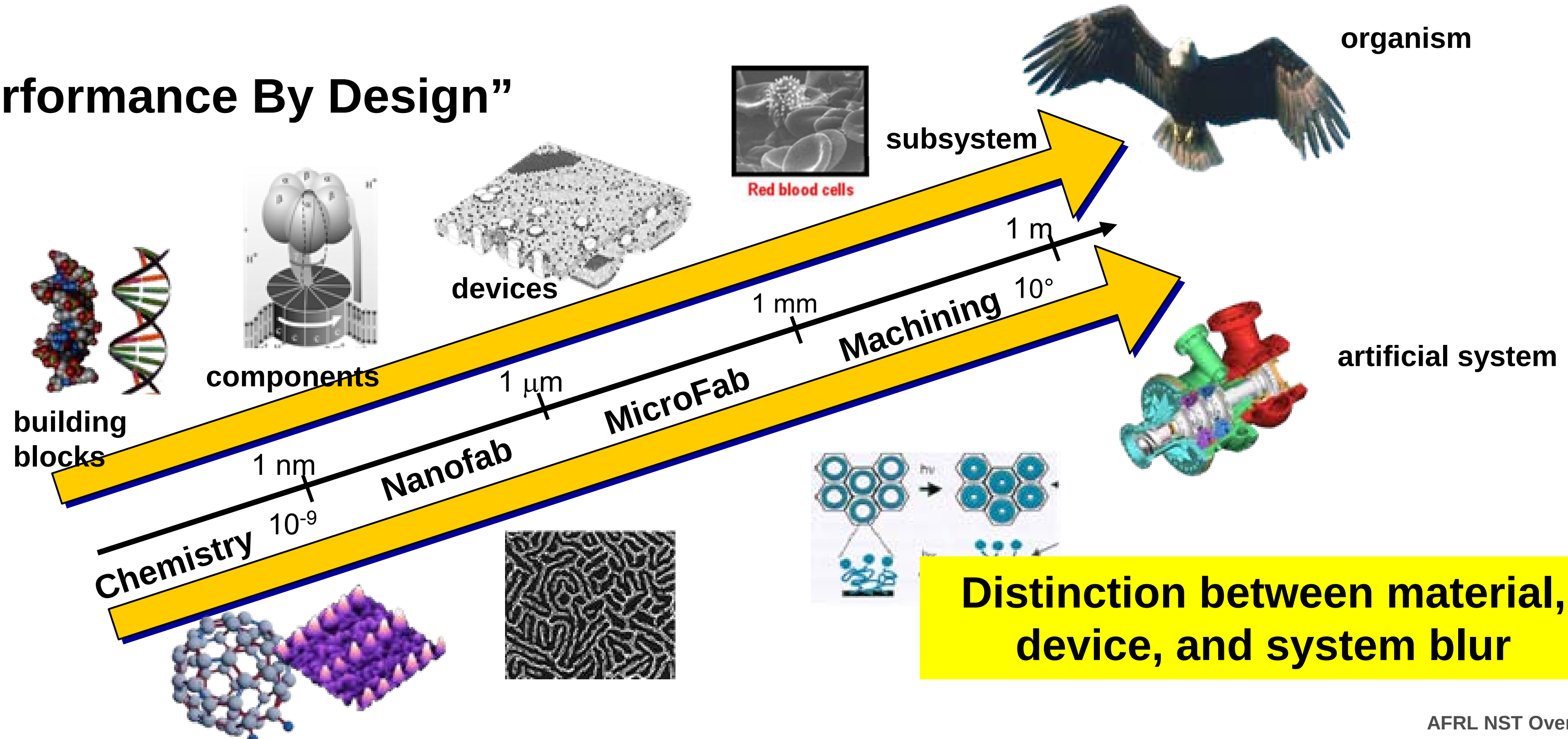
Circumvent material performance trade-offs

- Unique combinations

Strong	Responsive
Tough	Conductive
Durable	Optically active



"Performance By Design"



Distinction between material, device, and system blur

Nano-"Technology"?

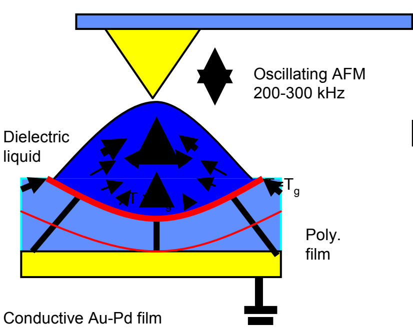
Technologies Utilizing NanoStructures

Nano-Enhanced Technologies

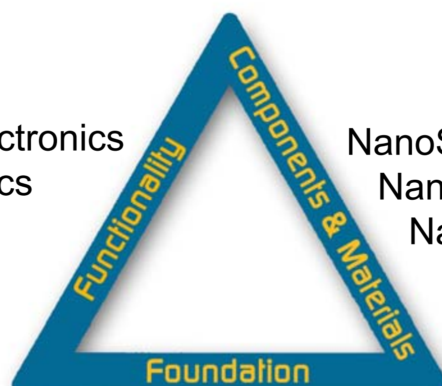
Coatings
Catalysts
Structures
Power Generation

NanoMachines
NanoDevices
NanoEngineering

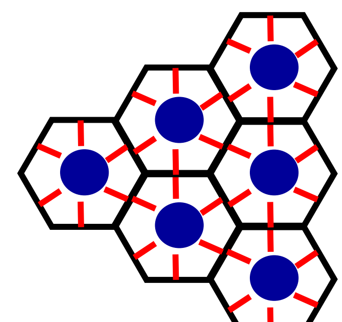
NanoScience



NanoElectronics
NanoMagnetics
NanoChemistry
NanoPhotonics



NanoStructures
NanoParticles
NanoComposites



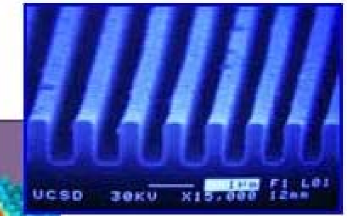
NanoMetrology
NanoAssembly

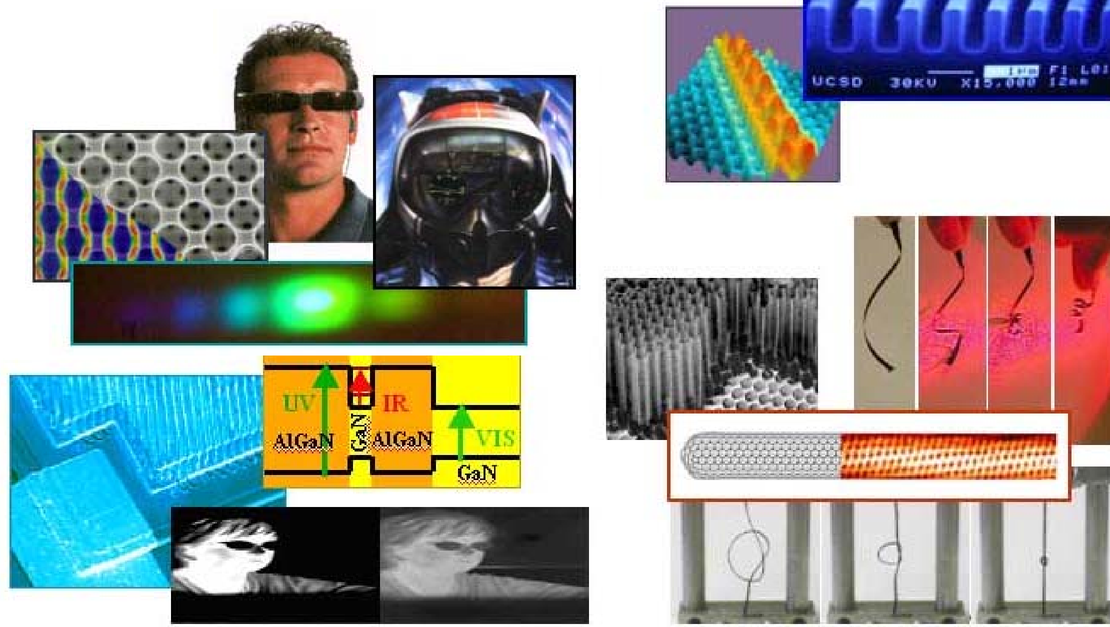
NanoFabrication
Theory&Modeling

AFRL NanoScience and Technology
An Evolving Revolution

AFRL has a rich history initiating and pursuing a broad range of nanotechnology research efforts
- a natural extension of the evolving research spectrum
- focused on achieving important AF requirements

Representative Examples of AFRL NST Programs





Emphasis

- **Understanding novel phenomena, properties and functions that occur on nm length scales**
- **Manipulation of matter at the nanoscale in order to control properties and functions to provide enabling capabilities**
- **New design, multi-scale integration, and validation techniques to achieve macroscale functionality enabled by a nanoscale response**

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- AN AF PERSPECTIVE OF NANOTECHNOLOGY
- NANOSCIENCE AND TECHNOLOGY IN AFRL: PAST AND PRESENT
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AFRL NANO R&D
An Established Foundation

ENERGY
- ✓ Advanced cathodes, anodes, batteries and capacitors (DE)
- ✓ Semiconductor phosphors and lasers (DE)
- ✓ THz lasers (DE, SN)
- ✓ Nano energetics (MN, PR)
- ✓ RF materials for groundplanes and thermal management (SN, ML, IF)

INFORMATION
- ✓ Dense, non-volatile memory and low-loss filters (AFOSR, IF)
- ✓ NEMS RF elements, picosats (IF)
- ✓ Swarm control algorithms (VS)

BIO/NANO
- ✓ Biological interactions and toxicity of nanoparticles (HE)
- ✓ Detection and neutralization of bioterrorist agents (HE)
- ✓ Bio-inspired technologies for sensing, data storage, toxin ID, warfighter monitoring and treatment (IF)

SENSORS
- ✓ Surface-enhanced detection and catalysis (AFOSR, ML, SN)
- ✓ Quantum dot detectors/emitters and multifunctional sensors (AFOSR, SN)
- ✓ Space weather sensors (VS)

MATERIALS
- ✓ Nanocomposites for multifunctional structures (AFOSR, ML, MN, PR)
- ✓ Ultrahigh temperature composites (AFOSR, ML)
- ✓ Interface science for tribology and corrosion (AFOSR, ML, PR, VA)
- ✓ Nanoscale materials for electronics (ML, PR)
- ✓ Nanotube and nanowire fabrication, assembly and characterization (ML)

STRUCTURES
- ✓ Self-healing and smart nanomaterials and structures (AFOSR, ML, PR, VA)

PROPULSION
- ✓ Nanocoatings for fuel components (PR)
- ✓ Nano electrojets (VS)

A partial list of broad nanotechnology areas historically addressed by AFRL

Advanced Detector Development

PROXIMITY INSPECTION

Small Feature Discrimination

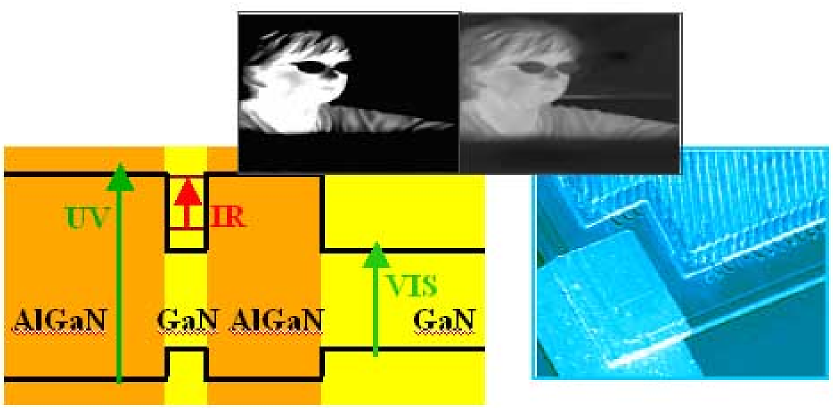
- ❖ **Polarization Detection in Quantum Wells**
  - ✓ *Sub-Pixel resolution*
  - ✓ *Contrast enhancement*
  - ✓ *Materials discrimination*

Target Status Determination

- ❖ **Multicolor IR Detection**
  - ✓ *Measure temperature for operational status*

Small, Maneuverable Sensing Vehicle

- ❖ **Monolithic Integration of Amplifier/ Detector/Electronics/Cooling**
  - ✓ *Increased speed*
  - ✓ *All wavelengths sensed with single FPA*
  - ✓ *Volume reduced 100-1000X*



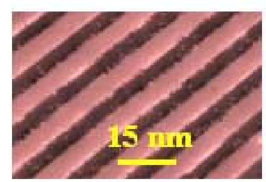
LONG RANGE DETECTION

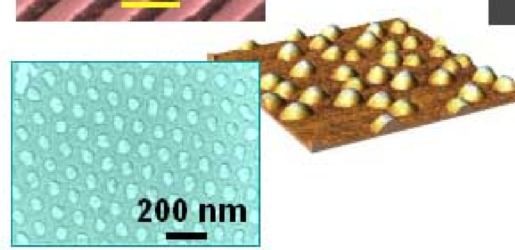
Faint Target

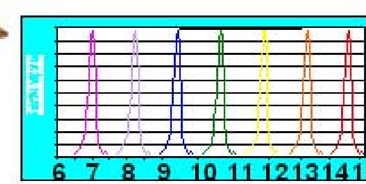
- ❖ **Quantum Interference in Quantum Wells**
- ❖ **Plasmonics**
  - ✓ *100X fainter signals possible*
- ❖ **Frequency Agility in Quantum Wells/Dots**
  - ✓ *Switch wavelength depending on whether sunlit or in eclipse*

Increased Range

- ❖ **Quantum Dots**
  - ✓ *Reduced cooling requirements*
  - ✓ *Optical efficiency and responsivity increases give 2-10X increased range*
- ❖ **Superlattices**
  - ✓ *Optical efficiency and responsivity increases give 3-10X increased range*



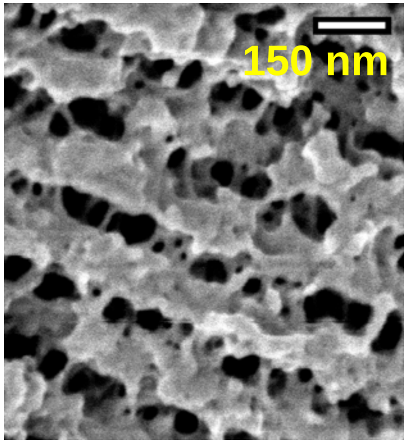


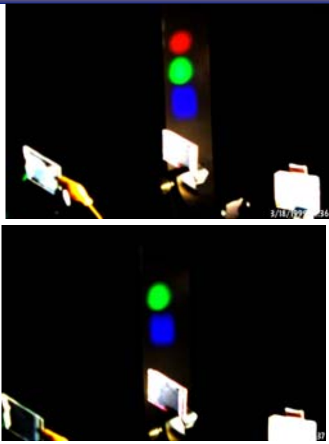


Tunable Optical Systems: Agile Optical Components

A new generation of image / information electronic displays

- ➢ Switchable photonic materials via spatially controlled nanoscale phase separation
- ➢ Switchable holographic optical elements replace bulky, immobile components





Military:

- ✓ Advanced Display Technologies
- ✓ Enhanced Imagery Support
- ✓ Helmet-Mounted Displays
- ✓ Laser Anti-Jamming Capability

Commercial:

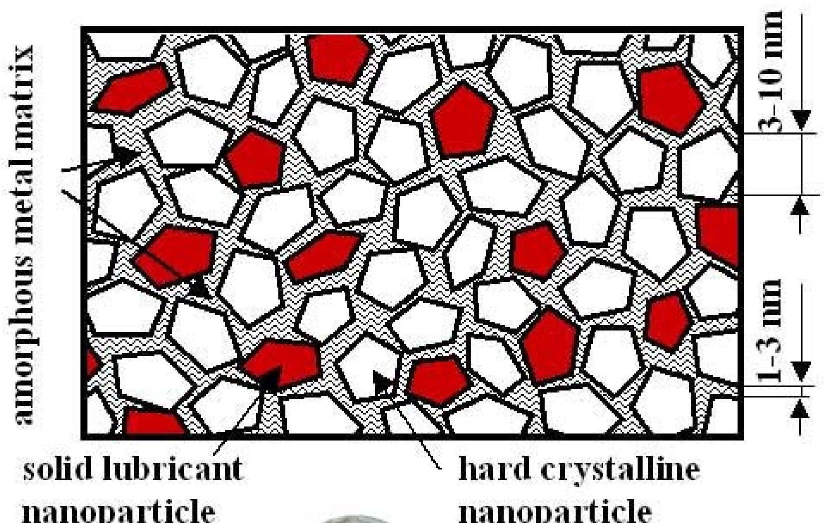
- ✓ Telecommunication routers
- ✓ Waveguide switches
- ✓ Automatic gain control devices
- ✓ Reflective displays
- ✓ Wearable displays
- ✓ DVD/HDTV viewers
- ✓ Electronic color filters

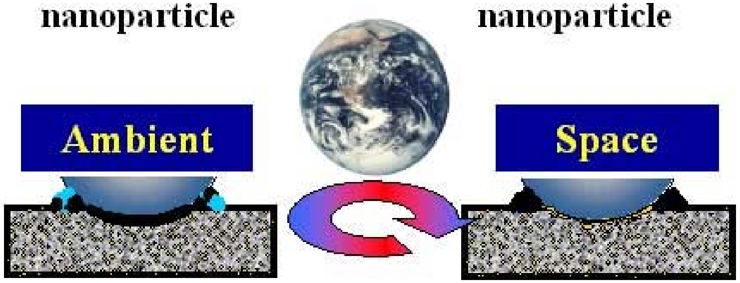
Next-Generation MultiFunctional Coatings

FRICTION AND WEAR CONTROL

Design unique nanostructured coatings

- ✓ Nano structures (layer thickness, grain size) permit unique properties
- ✓ Combine mutually exclusive properties - hardness, toughness, & low friction
- ✓ Friction and wear control in different extreme environments

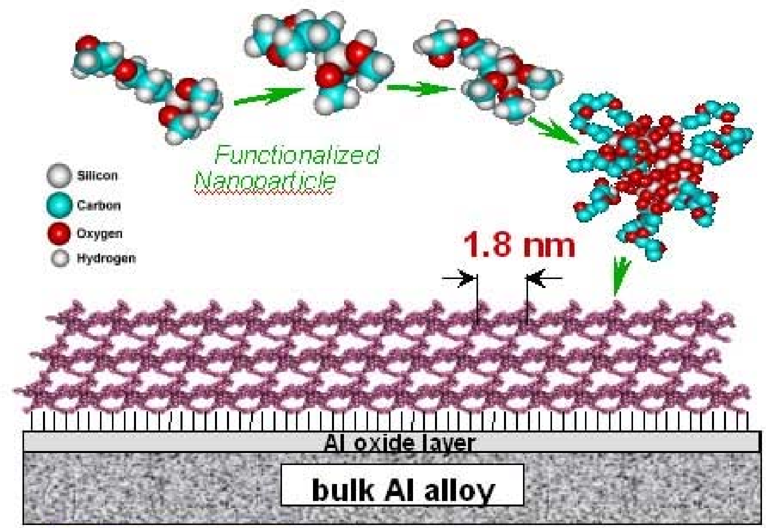




CORROSION PROTECTION

Self-assembled Nanophase Particle (SNAP)

- ✓ Functionally designed new coatings - siloxane macromolecules with epoxy functionality
- ✓ Fabricate nanosized (2.4 nm dia.) siloxane macromolecules using sol-gel process
- ✓ Assemble siloxane macromolecules via amine crosslinking to form useful coating



C-Nanotube Thrust: Providing the Foundations for Applications

Fabrication
Cost, Purity, Selectivity

Functionalization
'Handles'

Characterization & Modeling Tools

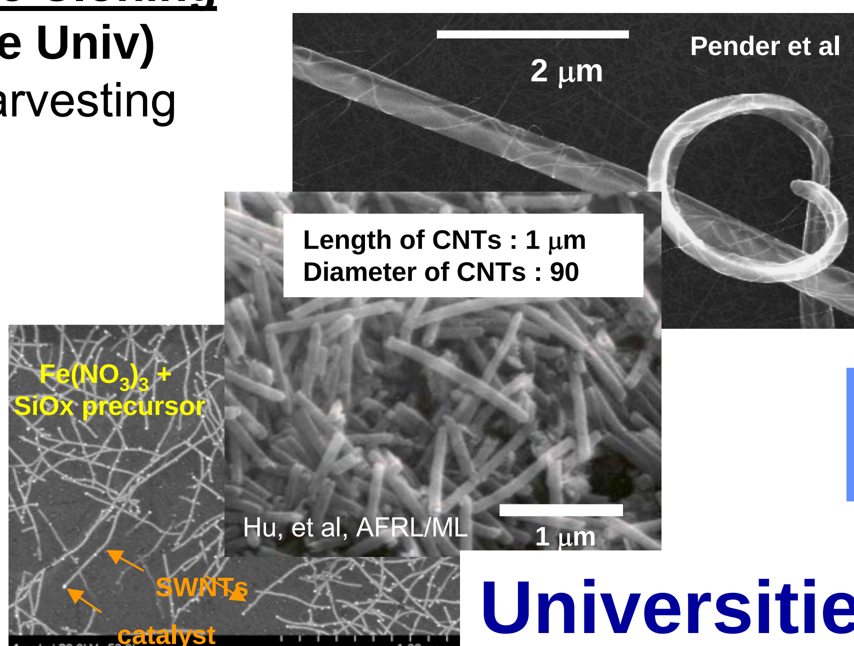
Integration
Ordered
Disordered

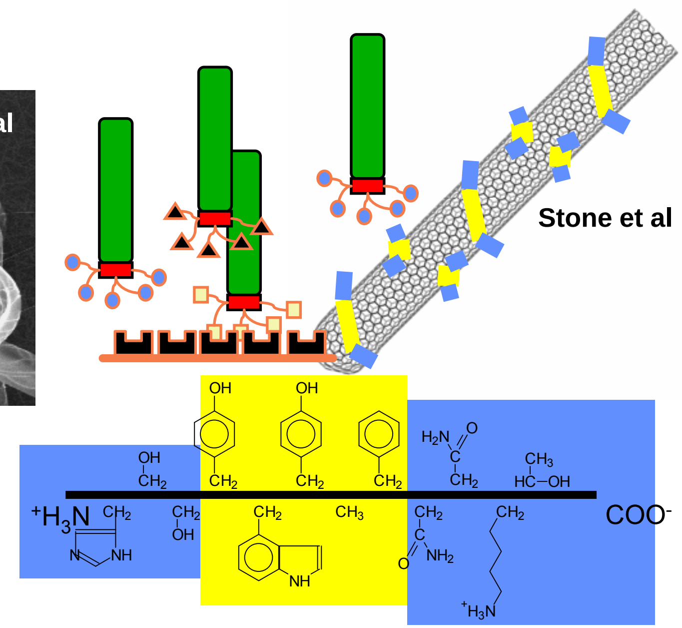
Applications

Sensors	PVs
Limiting	OLEDs
Emitters	NLO
Radar	Thermal
Antennas	Adhesives
LO	Shape Memory
	Etc..

Carbon Nanotube Cloning
(R. Smalley, Rice Univ)
- Separation & Harvesting
- Cleaving
- Activation
- Re-Growth

The Tool Box
- Subsistent Chemistry
- Manufacturing
- Modeling





Universities, AFRL, Industry

Bio – Nano Interface: Assembly

Objective:

Capitalize on biology's specificity:

site, function

size chemistry

for material fabrication

Impact:

Revolutionary capabilities for bottom-up Materials-by-design.

Approach: *Virus-like Particles* (VLPs)

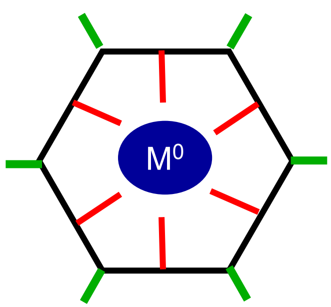
Virus Particles – *ideal* nano-building block

- 10-200 nm
- Icosahedra, rod, etc.
- Monodisperse
- Functional (pH gating)
- Site specific chemistry (exterior and interior)

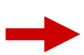
VLPs

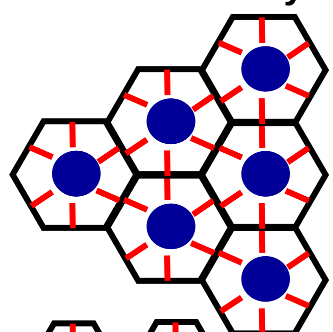
- Self-assembly of capsid protein
- Engineer protein sequence

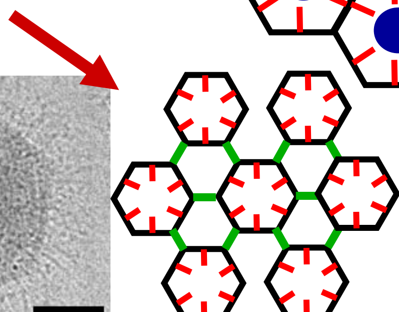
Nano-reactor



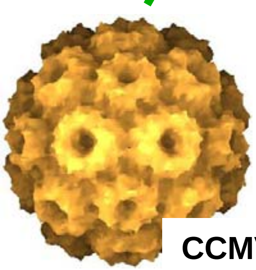
Directed Assembly

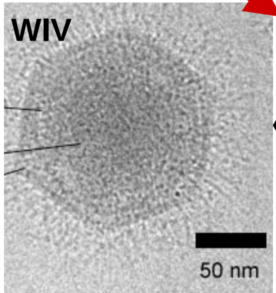


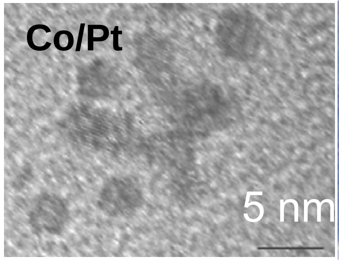




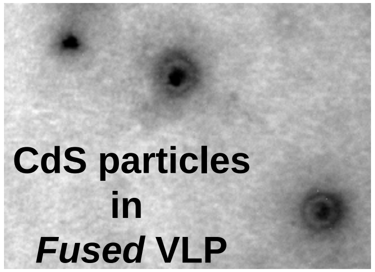
CCMV Virus

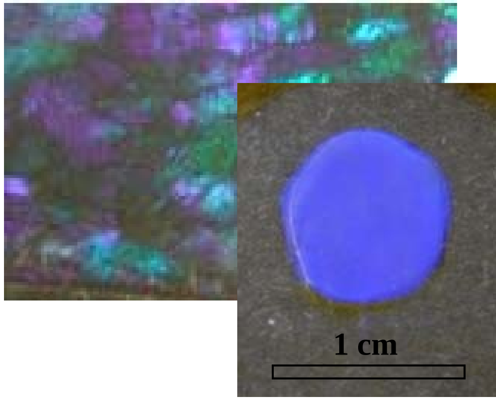






Assembly of WIV Optical Iridescence





AFOSR (BIC) Grantees

ML - CRDAs - AOARD

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- AN AF PERSPECTIVE OF NANOTECHNOLOGY
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- A STRATEGIC PLAN FOR THE FUTURE
- SUMMARY

AFRL NanoScience and Technology (NST) Working Group

Air Force Research Laboratory

Commander, Gen. P. Lamy

Chief Technologist, Dr. T. Cruse

NanoScience and Technology Working Group

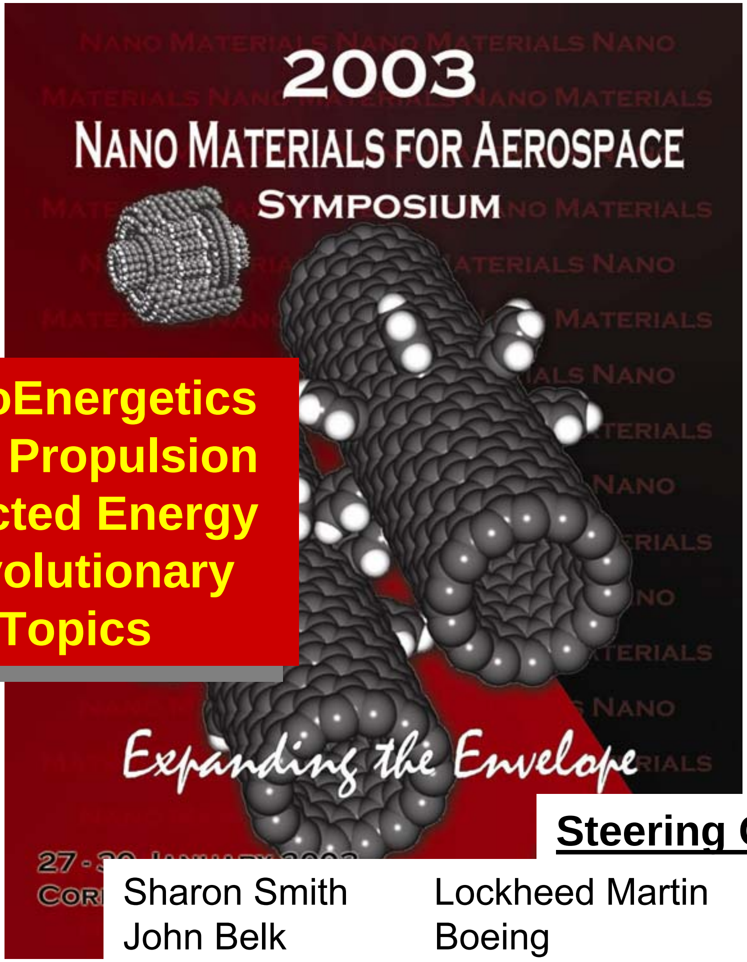
Chair, Dr. D. Miracle

Deputy/Executive Secretary, Dr. M. Shepard

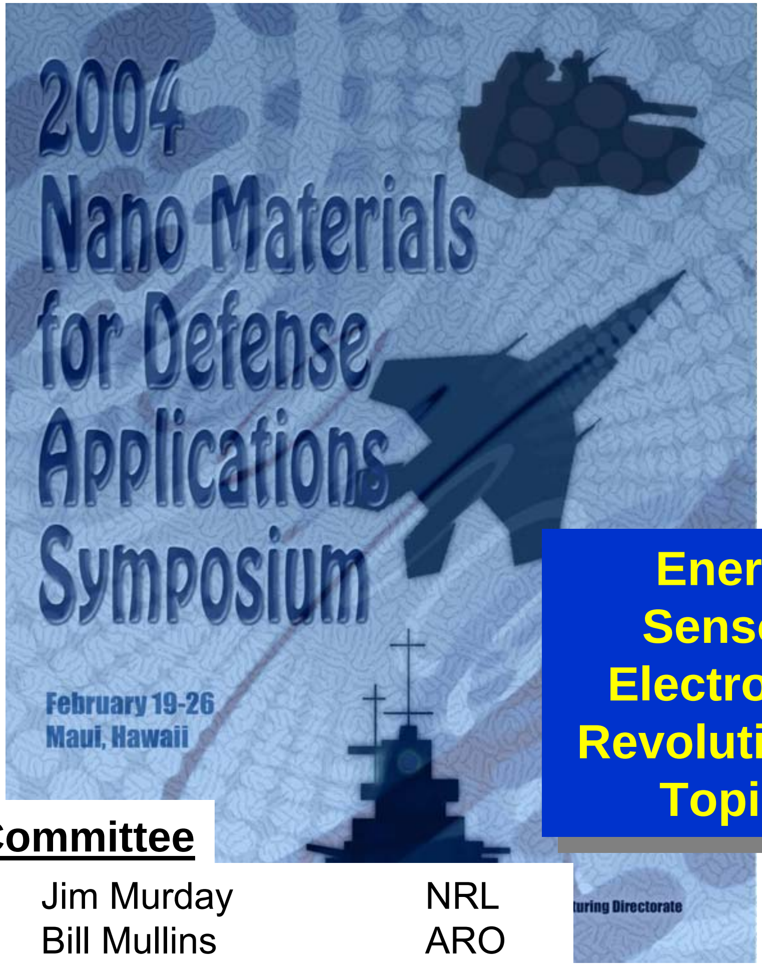
- **AF Office of Scientific Research (AFOSR)** POC, Dr. G. Pomrenke
- **Mat'ls & Manufacturing Directorate (ML)** POC, Dr. R. Vaia
- **Air Vehicles Directorate (VA)** POC, Dr. K. Ahlers
- **Munitions Directorate (MN)** POC, Dr. W. Cooper
- **Directed Energy Directorate (DE)** POC, Dr. D. Shiffler
- **Propulsion Directorate (PR)** POC, Dr. C. Bunker
- **Human Effectiveness Directorate (HE)** POC, Dr. K. Geiss
- **Sensors Directorate (SN)** POC, Dr. M. Freund
- **Information Directorate (IF)** POC, Dr. D. Burns
- **Space Vehicles Directorate (VS)** POC, Dr. D. Cardimona

NanoMaterials for Defense Conferences

Objective: Bridge the gap between revolutionary nanoscience for materials and DoD applications, needs and drivers



NanoEnergetics
Adv. Propulsion
Directed Energy
Revolutionary Topics



Energy
Sensors
Electronics
Revolutionary Topics

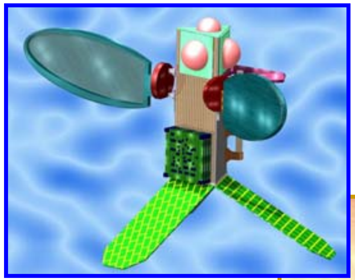
Steering Committee

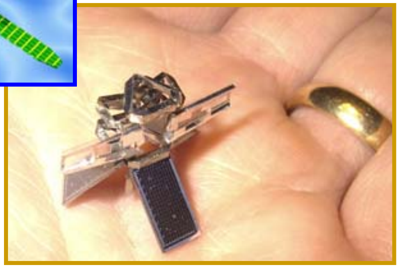
Sharon Smith	Lockheed Martin	Jim Murday	NRL
John Belk	Boeing	Bill Mullins	ARO
Terry Michalske	Sandia National Lab.	Harold Weinstock	AFOSR
Wade Adams	Rice University		

AFRL NST STRATEGY
Focused on AF Needs

Anticipate & determine topics most significant to the AF
- CONOPS, AF Vision 2020, Long-Term Challenges (LTCs), Warfighter Technology Areas (WTAs), NRC study

NST topic selection criteria
- "If we don't do it, it won't be done."
- cross-Directorate interactions





DARPA UC Berkeley
non-flying model

Examples of new capabilities:
- high-energy capacitor (2-3X) (near term)
- THz processing cube & Tb/cm^2 storage (near term)
- increase explosive yield by 300-500% (mid term)
- dragonfly (maneuvers, sensing, ATR, stinger) (long term)

Process and Outcome
- several technologist-level workshops held from 2001 to 2003 to develop AFRL-wide technical strategy
- final strategic plan approved by AFRL Corporate Board October 2003
- funding approved for 6.1 portion of the strategic plan beginning in FY06
- additional advocacy is currently underway for 6.2 investment

Nanotechnology Linkage to LTCs

Red: Included in the AFRL NST Plan

Long Term Challenges	Nanotechnology Links
Precise Finding and Tracking:	**Nanosensors** - multi-spectral sensing, integrated nanoelectronics and nanophotonics, high speed target acquisition & image processing, enhanced infra-red target recognition
Command and Control:	**Nanodevices** - Nano-processor; orders of magnitude increase in computing power, information storage, and processing abilities; radically improved decision making. **Quantum Computing** - eliminate multiple design iterations and prototype testing; extremely fast image reconstruction.
Controlled Effects:	**Nanoscale Energetic Materials** - improved energy release rates, accelerated burn, smaller munitions, safer propellants **Nanoelectronics** - Counter radiation effects
Sanctuary:	**Nanosensors** - airborne and space-based long range detection; multi-spectral awareness **Coatings** - revolutionary dynamic stealth
Effective Aerospace Persistence:	**Nanoparticles and Nanostructured Materials** - advanced fuels, lubricants and additives; bearings, power generation, storage and delivery; self-healing structures; smart skins; high performance structures **Nanoelectronics** - Pico-satellites, spaced-based RADAR

AFRL NST STRATEGIC PLAN

Six Selected Topics

Materials Area
1. Tailorable Dielectrics
2. Reconfigurable Optical Response
3. Adaptive Structural Materials
4. Thermal Control Materials
Energy Area
5. Energetics on the Nanoscale
6. Nano-enhanced Power Technologies
Devices Area
7. Quantum Confined Optical Sensors
8. Nanotechnology for RF
9. Nano Signal Processors
Bio-Nano Area
10. Bio Interactions of Nanostructures
Cross-Cutting (foundations)
11. Self-assembly of Nanostructures
12. Nano-Micro-Macro Interfaces
13. Modeling And Simulation

Blue: Selected topics

Red: Essential foundations

Nano Engineered Materials

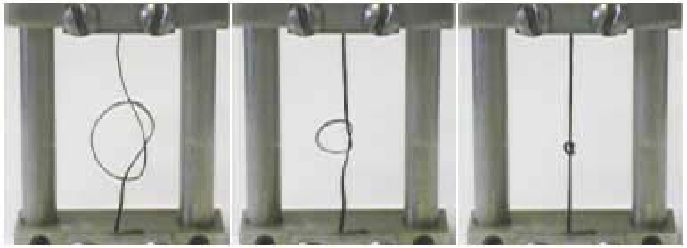
Adaptive Structural Materials and Coatings

Description
– nanostructured materials with tunable mechanical properties or durability

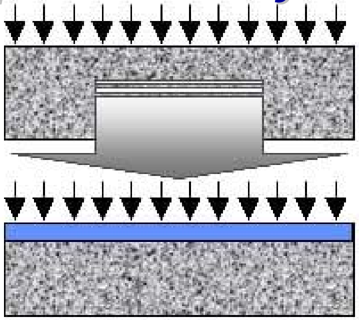
Nature of experimental demonstration
– self-passivating/repairing coatings
– airfoil warping

Payoff to AF- Adaptable mechanical properties enable:
– futuristic concepts of airfoil warping
– surface-directed flight control for UCAV and missiles
– self-repairing will increase service life
– actuators for space antennae deployment
– heat tolerant skin for satellites

Actuation



Self-generating protective layer



Self-adapting lubriciousness

Nano Energetics

Energetics on the Nano Scale

Description

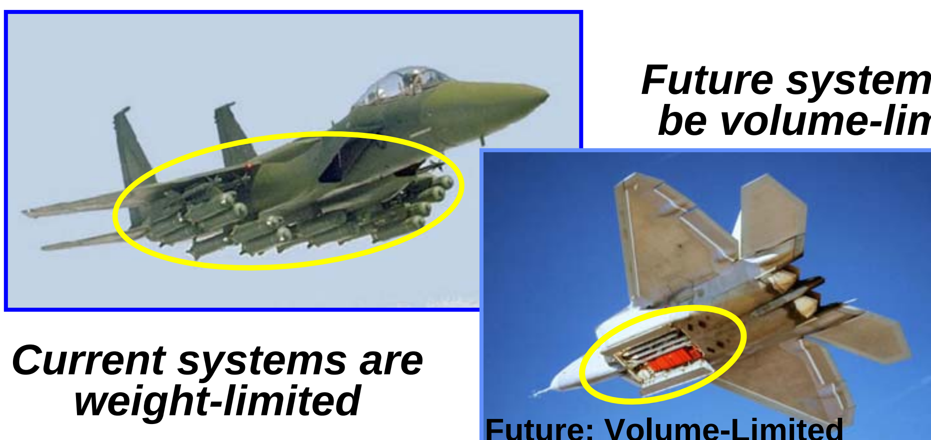
- nano reactive materials, additives, coated powders, & laminates for munitions and propulsion
- munitions must decrease in size & require much higher lethality

Nature of experimental demonstration

- nano-propellants and nano-munitions

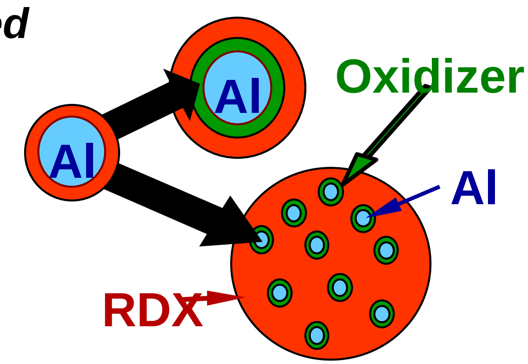
Payoff to AF

- munitions with 5-10x higher lethality (at same mass)
- improved propellant efficiency increases with est. $1.5-2B/yr fuel savings
- affordable access to space via efficient propellants, high thrust/weight
- enables global strike/response

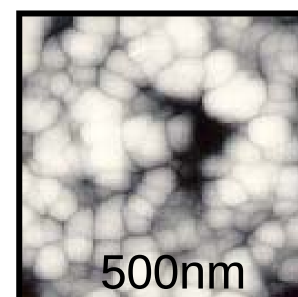


Current systems are weight-limited

Future systems will be volume-limited



Nano Al



Nano Structured Devices

Quantum Confined Optical Sensors

Description

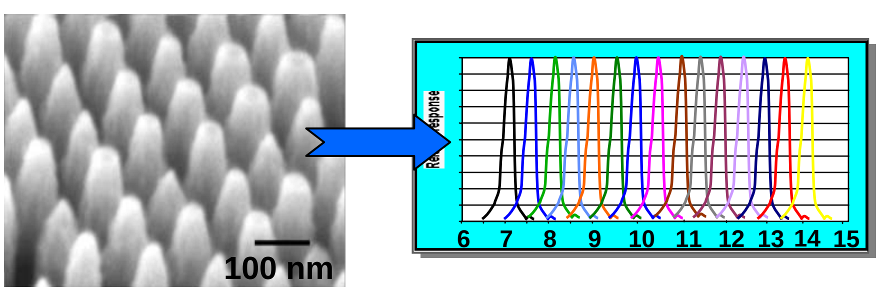
- quantum engineered materials, devices, and focal plane arrays (FPAs) for high-performance optical sensing & communication
- tailored for specific needs in UV, IR and THz

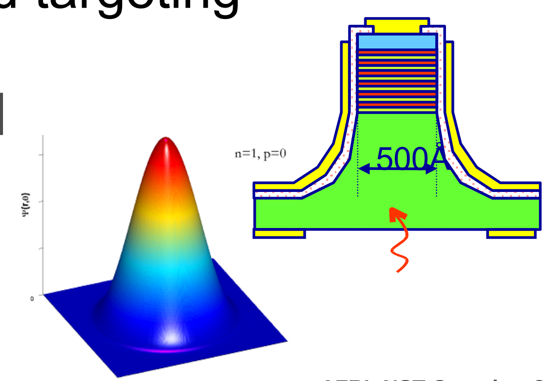
Nature of experimental demonstration

- VLWIR 256x256 FPA based on superlattices
- agile FPA based on quantum dots

Payoff to AF- New capabilities include:

- multiple narrow wavelength bands combined in a single pixel
- smart detector arrays adjust to scene conditions to optimize signal
- higher operating temperatures without sacrificing performance
- high bandwidth and secure COMM ID for tracking and targeting
- addresses multiple WTAs/LTCs/CONOPS





Nano Structured Devices

Nanotechnology for RF

Description

– nano-materials and nano-devices as enabling components for ubiquitous remote sensors, sensor web, and ISR for RF systems

Nature of experimental demonstration

– thermal control materials

– integrated RF system (nano-FETs, materials)

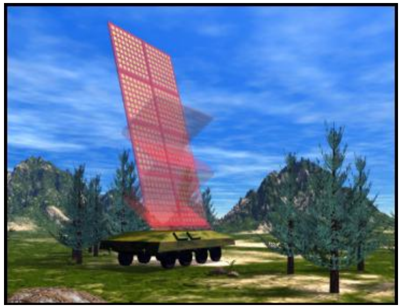
Payoff to AF- NST enables revolutionary capabilities

– nano-processors enable information dominance via high-bandwidth secure communications, microsat constellations, UCAVs, and SBR constellations

– nano-integration enables: conformal multifunctional structures (wings, etc.)

– knowledge and predictability of all forces (friend, enemy, neutral)

– persistent battlespace awareness and persistent global surveillance



OUTLINE

- AN AF PERSPECTIVE OF NANOTECHNOLOGY
- NANOSCIENCE AND TECHNOLOGY IN AFRL: PAST AND PRESENT
- A STRATEGIC PLAN FOR THE FUTURE
- SUMMARY

NanoScience and Technology: Challenges

Fundamental

predictive processing-structure-property relationships

Properties
Continuum descriptions
Properties of nanoelements
Data handling

Characterization
Interconnectivity
Reproducibility
Error & defect acceptability

Technological

integration of new concepts and tools

identification of impact

Infrastructure
Engineering tools
Life prediction
Life-cycle

Design paradigms
Data handling
Rapid screening
Costs benefit
Information in and out

Commercialization

producibility

Appropriate process models, quality control tools and manufacturing techniques

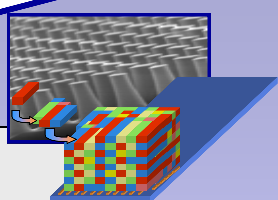
Extent of Process Control Required Vary with Market Size

Commodity Needs, Low Volume Requirements Vs. Niche Applications

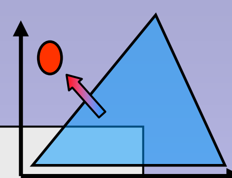
Nano ⟶ Tailoribility ⟶X⟶ Commodity

AFRL NST STRATEGIC PLAN

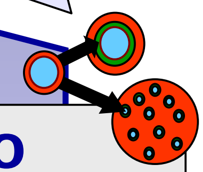
Focused on Achieving Warfighter Needs



Nano Structured Devices



Nano Engineered Materials



Nano Energetics

Foundation & Tools:

Modeling - Nano Assembly & Fabrication - Characterization

SUMMARY

AFRL generates revolutionary technology options for the warfighter and preempts technology surprise

QUESTIONS?

BACKUP CHARTS

NANOTECHNOLOGY AT AFRL

A tradition of excellence in aerospace R&D

- nanotechnology has been an integral part of the AFRL technology program as a natural progression of the aerospace R&D enterprise
- important advances have provided compelling AF operational capabilities

A strong strategic plan focused on AF needs

- focus areas include materials, devices and energetics

Funding has been obtained for the AFRL NST Strategic Initiative

- basic science portion funded
- effort is currently underway to obtain resources necessary to capitalize on fundamental scientific advancements

AFRL NST STRATEGIC PLAN
PROCESS

Jun 01 and Aug 01: AFRL Technologist Workshops
- Purpose: Convene grass roots workshop of AFRL technologists to discuss and define a coherent and integrated AFRL NST strategy
- Representatives from each AFRL Directorate

Aug 03: AFRL NST Workshop (>60 S&T, 10 TDs, AFIT*)
- Purpose: Actionable focused & high-payoff plan
- Focus areas: Bio-nano, Energy, Devices, Materials
- First round: 42 topics
- Second round: 1-4 topics per focus area
- Result: 13 topics, 3 cross-cutting topics
- Final 6 topics selected by grading/voting

17 Sep 03: Presented to Research Council

24 Oct 03: Presentation to Corporate Board
- Accepted as official AFRL Initiative

*** AFIT: Air Force Institute of Technology**

Architects of Advanced Technology

AFRL's mission is to be the Air Force Agent for identifying and providing advanced, affordable, and integrated technologies that keep our Air Force the best in the world. Its partners and teammates include both academia and industry.

New Organization. New Mission.

Now the largest laboratory in the Department of Defense (DOD), a vital national asset, and the world's preeminent military aerospace science and technology (S&T) organization. AFRL remains dedicated to discovering and developing military-relevant technology for space, air, and command and control, and the people who operate and maintain those systems.

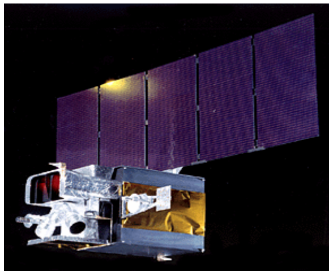
An essential goal of AFRL's organization is to tie the Air Force R&D mission more closely to the requirements of the warfighter. AFRL is now better aligned and more closely "tuned-in" than ever before to support the Air Force's 21st century vision of "Global Engagement." AFRL understands the critical importance of listening to what the customer wants and then providing it in a timely, cost efficient manner.

Organized for Results

AFRL is organized along technology disciplines into nine technology directorates plus the Air Force Office of Scientific Research. Each technology directorate performs, procures, and synthesizes basic research, exploratory technology development and advanced technology development within its areas of responsibility with a clear mandate to provide integrated solutions to customer requirements.

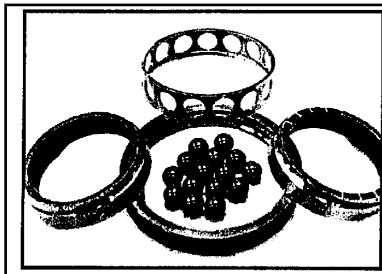
Nano Inorganic Clusters

Satellites & Space Systems



- Max Space Resistance - LEO, AO, UV
- 10% Lower Density
- High Modulus
- Resins for all Structural Applications

Nanostructured Lubricants



BEARINGS

- Current lubricants limited to 400º F
- POSS based lubricants T_{dec} = 590º F
- Desire a fluid with working temperature range of -40º to 600º F (IHPTET)

Rocket Propulsion

- Nanostructured Pulsed Plasma Fuel Additives
  - 10-20% Reduced Consumption
  - 17% Improved ISP of Current PPT
- Solid Rocket Motor Ablatives
  - cuts Insulation weight 44%
  - increases Booster Payload 7.4%

Jet Canopies

- Mach 2.x speeds limited by plastic canopy
- Target Engagement Times can be reduced by increasing flight speed

Computational Design of Nanomaterials

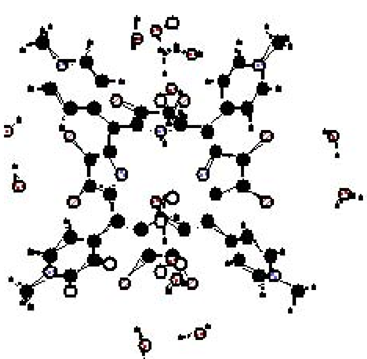
Objective: **Develop and apply mathematical & computational methods to design materials at the nano-scale:**

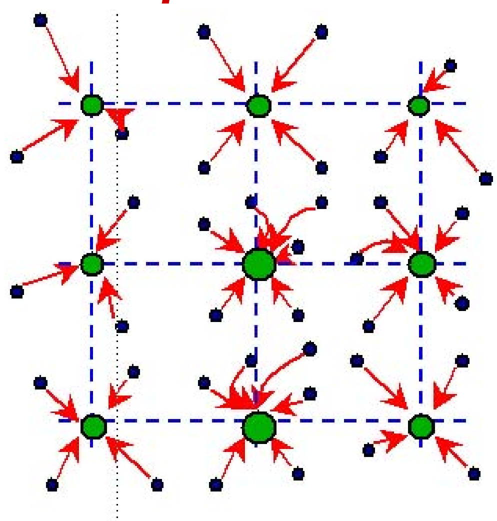
Integration of materials properties across length- and time-scales for macromolecular systems; biologically inspired materials design; complex materials, such as liquid crystals; advanced scientific computing/simulation algorithms

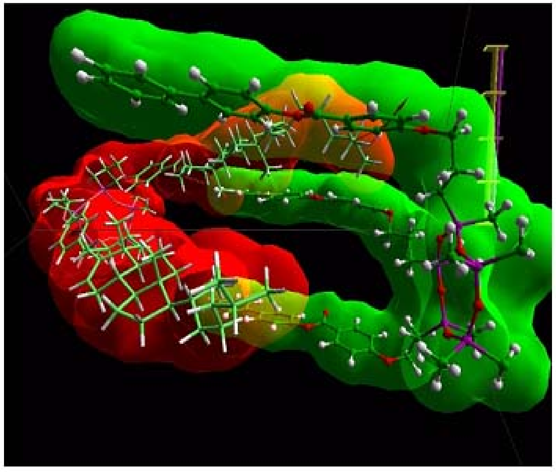
Success: **Design of nanomaterials for Air Force applications with newly developed multiscale approaches:**

Large-scale and long-time molecular dynamics using fast multipole & multi-grid methods enable simulations or liquid crystals at the nano-level; effective fragment potential method enables study of nano-optical materials in the condensed phase; newly developed optimization techniques enable large scale biomolecular structure determination

Wide-spread impact on the fundamental design of nanomaterials







NRC Study Recommendations

Red: Included in the AFRL NST Plan

NRC STUDY: HIGH INVESTMENT PRIORITY AREAS		
Area	Technology Area	Current TD Priority*
Electronics H/W	Space electronics/photonics/magnetics	PR, OSR
	Nanoscale fabrication techniques	PR, ML, VA, SN, OSR
	Nanoscale materials for electronics/photonics/magnetics	PR, ML, SN, OSR
Information Processing	Data fusion	HE, IF, SN
	Distributed and autonomous systems	HE, VA, IF, SN
	Algorithms, architectures and S/W for codesign	OSR, IF
Sensors	Distributed sensors & swarms emergent behavior	VS, VA, SN
	New nanoscale materials for sensors	VS, ML, SN, OSR, HE
	EM sensors, UV to RF	ML, SN, OSR
	Hyper- and multispectral sensing	ML, SN, OSR
Structural Materials	Coatings for improved friction & wear reduction	PR, ML, OSR
	Coatings for low maintenance	ML
	Multifuncitonal structures for self healing	PR, ML, VA, OSR
	Multifunctional structures for Low Observable (LO)	ML
Launch Vehicle Propulsion	Nanocoatings for fuel components	PR, OSR
	Nano powder aluminum propellants	PR (ML), OSR
Manufacturing Technologies	Packaging of embedded devices	PR, VA

* Curently funded activities

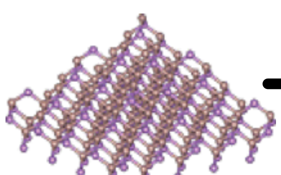
SEMICONDUCTOR QUANTUM DOTS

A new generation of electro-optics and sensors

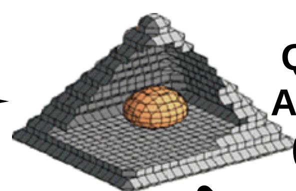
- room temperature lasers and detectors at infrared wavelengths
- single electron transistors
- tera-byte quantum memory storage

Modeling (AFRL/SN, JPL):

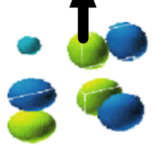
- ✓ atomistic description of electron structure and transport
- ✓ provides tool to accelerate material and device development



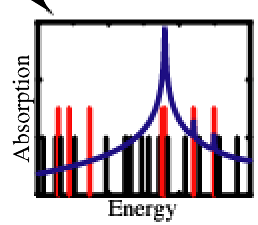
Structure (millions of atoms)



Quantum Dots Artificial Atoms (size ~20nm)



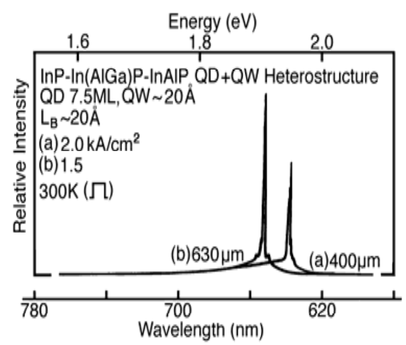
Atomic Orbitals size: 0.2nm

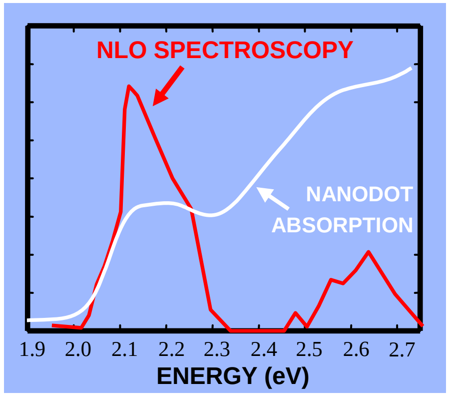


Designed Transitions
Sensors, Lasers, Spintronics

Characterization (AFRL/SN, UT Austin):

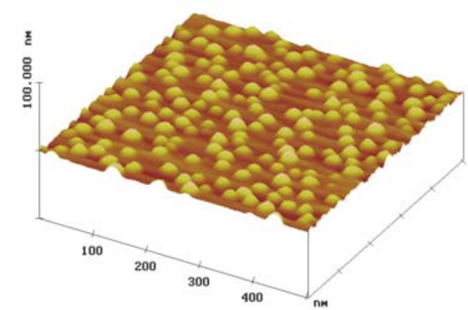
- ✓ non-linear optical quantum dot characterization





Processing (AFRL/ML):

- ✓ self-organized InGaAs quantum dots



Foundational

Objective:

Nanoscale, soft-matter (polymers, gels, biological materials) patterning tools

Impact:

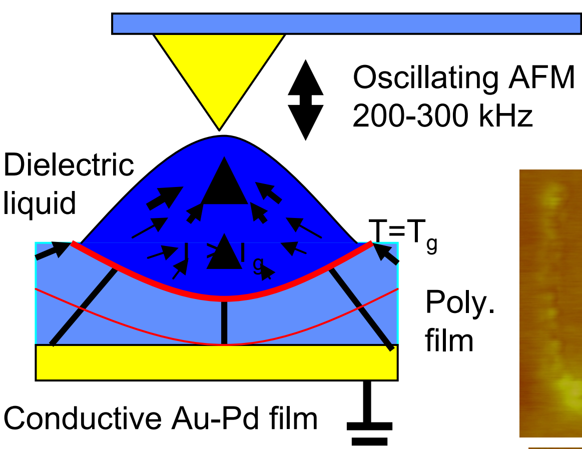
- Scientific: manipulate nanoscale phenomenon and structure
- Technological – data storage, integrated device (electronics, fluidics, mechanics) assembly

Accomplishments:

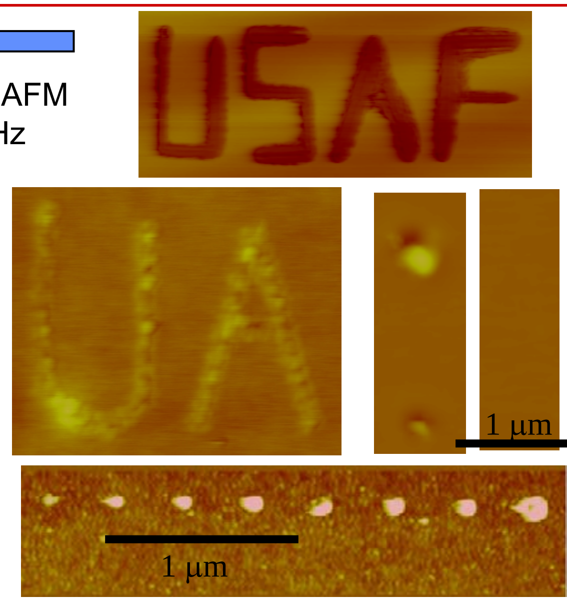
AFM Electrostatic NanoLithography (AFMEN) localized Joule heating of attolitters of polymer followed by electrostatic distortion

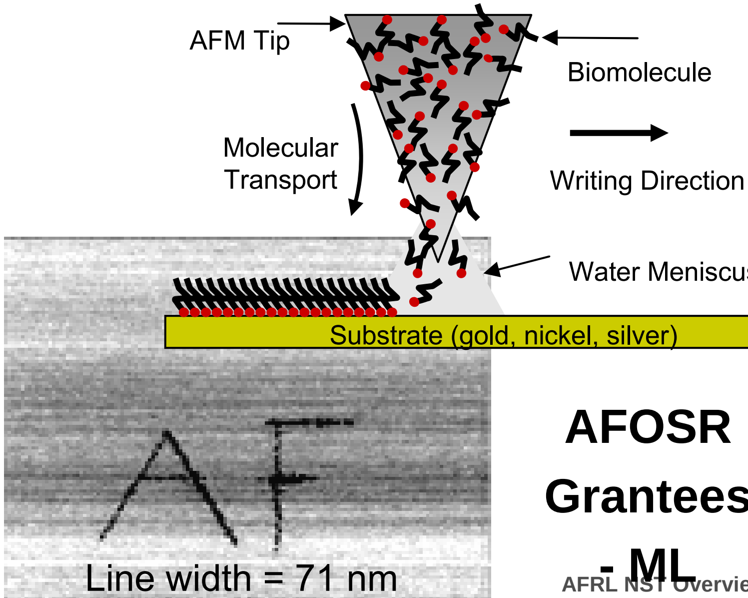
- 1-10 nm↑, 20-50 nm↔
- <<msec feature generation
- ~500 Gb/in^2 ; AFM array compatible
- Rewritable

Dip-Pen Nanolithography of bio-molecules, such as catalysis peptides for inorganic



AFOSR Grantees - STW21 - ML





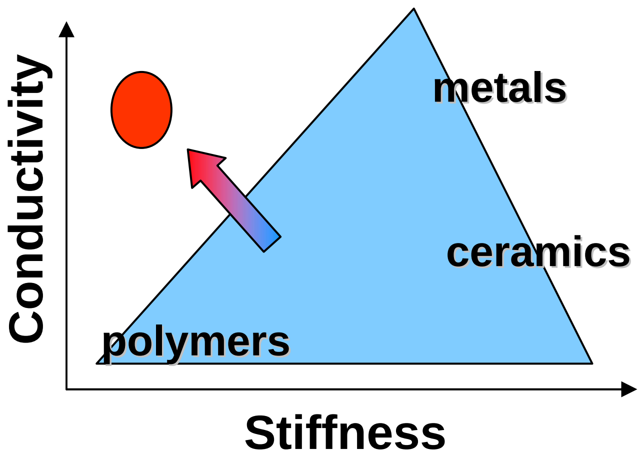
AFOSR Grantees - ML

Nano Engineered Materials

Potential Return on Investment

Investments in:

- ✓ nanoengineered composites
- ✓ high-energy-density materials
- ✓ adaptive & self-healing materials
- ✓ nanostructured (nanowires, tubes, etc.) electronic/opto-electronic materials
- ✓ quantum mechanical & molecular dynamics modeling



Offer potential for:

- ✓ 10-100x stronger materials - lightweight aerospace vehicles
- ✓ 2X increase in temperature, 100X lifetime materials for turbine engines
- ✓ ability to simultaneously optimize multiple desired materials characteristics, e.g. electrical and structural characteristics
- ✓ adaptive materials - dynamic stealth and improved survivability of aerospace assets

Nano Engineered Materials

Tailorable Dielectric Susceptibility

Description

– LO and low-loss dielectrics (capacitors, RF substrates)

Nature of experimental demonstration

– balanced high energy capacitor

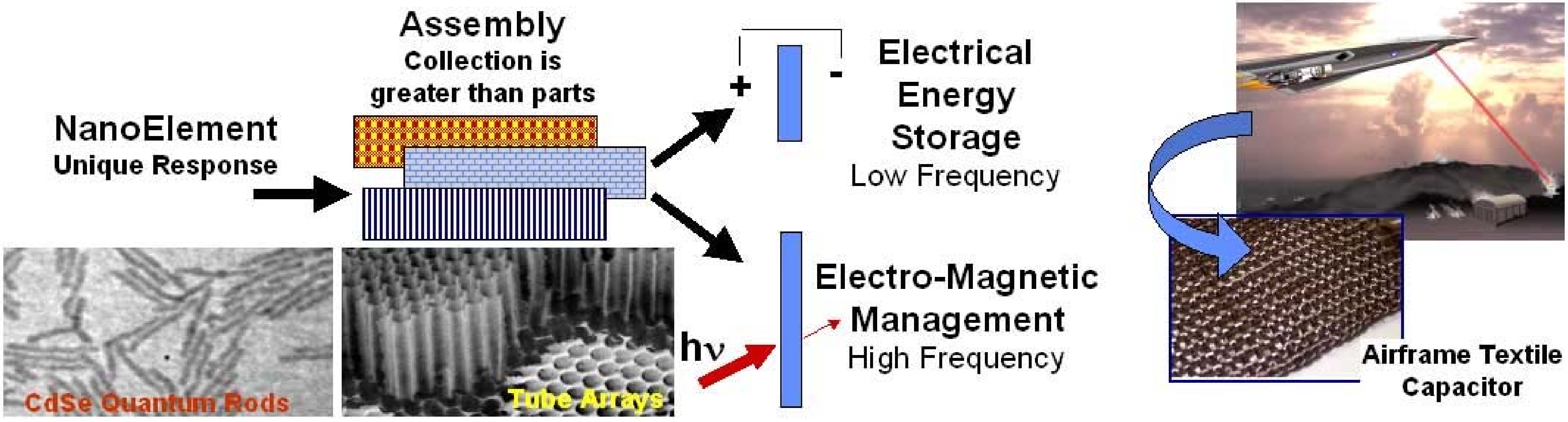
– large area panel with agile EM radiation management

Payoff to AF

– high energy capacitors for tactical lasers, satellites

– load bearing tailorable RF & μ-wave antennae for sensor craft and UCAV

– tailorable electromagnetic radiation management for new threats



Nano Engineered Materials

Reconfigurable Optical Response

Description

– materials that alter refractive index from thermal, electrical, or optical stimuli

– light manipulation at sub-wavelengths, photon localization, non-linear optics

Nature of experimental demonstration

– ultra-fast (ns), broad spectral (10 -100 nm) responsive optical element

– large area, low-cost optical appliqué

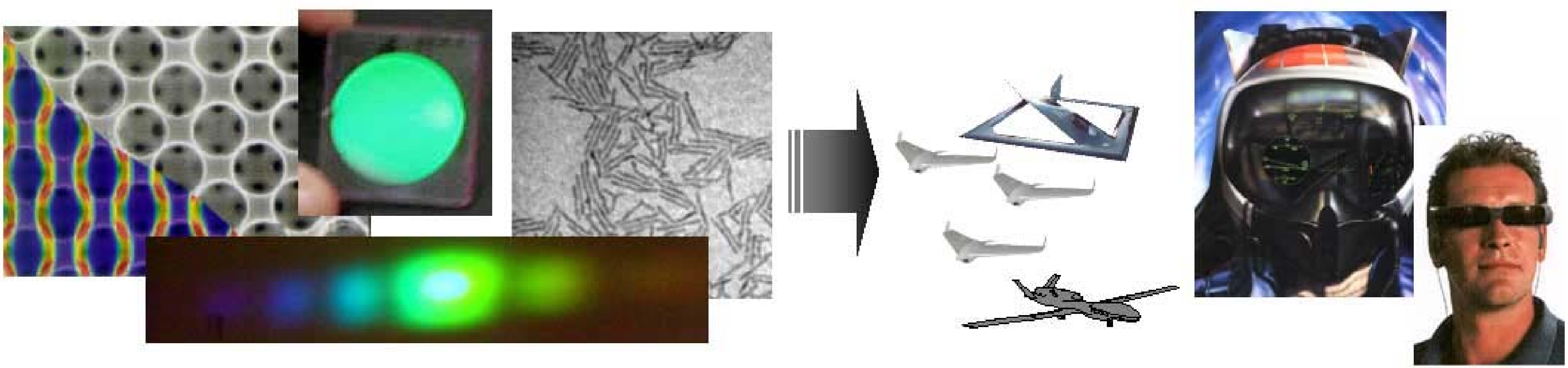
Payoff to AF

– enhanced system hardening for agile response to future threats

– reduce volume and increase robustness of sensor systems

– agile source/receiver for secure communication & information processing

– ultra-sensitive cavity resonators able to detect a single (or a few) molecules

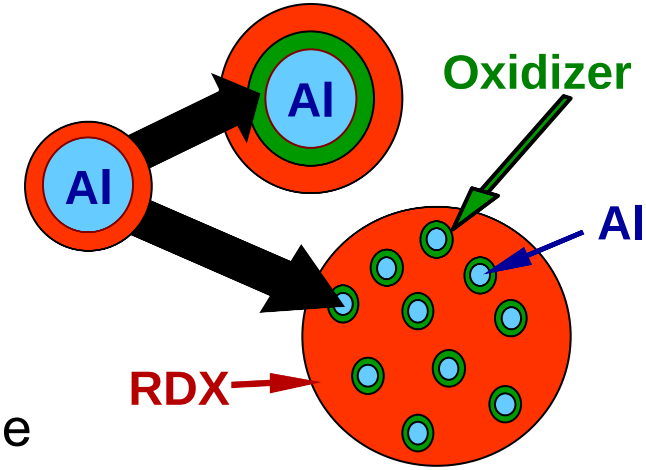


Nano Energetics

Potential Return on Investment

Investments in:

- ✓ nanostructured explosives and fuel additives
- ✓ nano controlled catalytics
- ✓ nano engineered photovoltaics



Offer potential for:

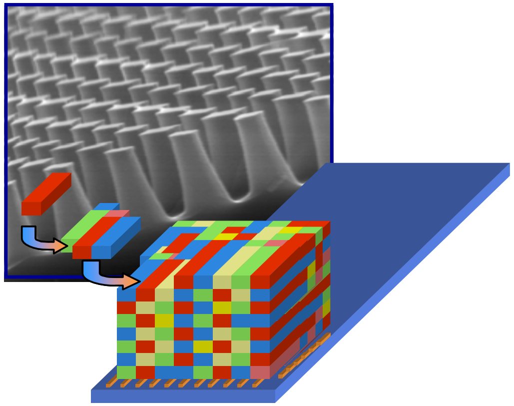
- ✓ 10-100x improved power density/energy release rate/ package volume and increased safety – miniature smart munitions
- ✓ improved munitions blast control – better coupling of energy to target, lower collateral damage
- ✓ stable, 5-10x more efficient propellants – safer, high-thrust-to-weight-ratio propulsion systems, increased weapon loadout, affordable access to space
- ✓ improved power generation, conditioning & control for aerospace vehicles – enhanced global reach

Nano Structured Devices

Potential Return on Investment

Investments in:

- ✓ nano processing/comm devices, circuits, ICs
- ✓ nano actuators, controllers, sensors, photonics & integrated NEMS
- ✓ revolutionary computing architectures – quantum, molecular, optical
- ✓ quantum communications & cryptography



Offer potential for:

- ✓ 10-1000x higher speed, lower power higher density electronics – on-board processing for target tracking/ID and autonomy
- ✓ exponential speed up for hard problem solution, e.g. scheduling, multi-asset control
- ✓ 10-1000x smaller sensors, actuators & NEMS – new surveillance capabilities, e.g. microsat constellations, UAVs, UCAVs and large, space-based membrane apertures
- ✓ high-bandwidth, secure communications - information dominance